REPORT DOCUMENTATION PAGE

AFRL-SR-AR-TR-04-

0035

1. REPORT DATE *(DD-MM-YYYY)*

2. REPORT TYPE
Final Report

3. DATES COVERED *(From - To)*
Nov 1, 00 - Oct 31, 03

4. TITLE AND SUBTITLE
An Agent-Based approach to Optimal Configuration Design with Application to Manufacturing Process Planning

5a. CONTRACT NUMBER

5b. GRANT NUMBER
F49620-01-1-0050

5c. PROGRAM ELEMENT NUMBER

6. AUTHOR(S)
Dr. Jonathan Cagan

5d. PROJECT NUMBER

5e. TASK NUMBER

5f. WORK UNIT NUMBER

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
Department of Mechanical Engineering
Carnegie-Mellon University
Pittsburgh, PA 15213

8. PERFORMING ORGANIZATION REPORT NUMBER

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
Department of the Air Force
Air Force Office of Scientific Research
4015 Wilson Blvd.
Arlington, VA 22203-1954

10. SPONSOR/MONITOR'S ACRONYM(S)

11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT

Distribution Statement A: Approved for public release. Distribution unlimited

13. SUPPLEMENTARY NOTES
DODAAD CODE: 97668
AFOSR Program Manager: Lt. Col. Juan R. Vasquez

14. ABSTRACT
The project focused on 3 goals:
1) Process instantiation. A probabilistic approach was used to determine which agents to select to instantiation a configuration through parameter selection.
2) Configuration optimization: The parameter optimization algorithm was modified to select and optimize sequences as well as optimize parameters. The advantage of the approach is that it is open-ended; there is no preconceived assumption of what sequences might be valid or optimal. Configuration agents were developed and integrated with the parameter agents to effectively optimize both process selection and parameters, concurrently.
3) Effective management of the agent process: Two approaches were taken. First, a strategy for learning across problems using findings in cognitive science was applied to our agent-based method. Second, using organizational models, a collaborative approach was formalized and implemented, allowing the agents to interact and make group decisions of how to best solve the configuration and parameter optimization problem.

15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT	b. ABSTRACT	c. THIS PAGE			Dr. Jonathan Cagan
					19b. TELEPHONE NUMBER *(Include area code)*

Final Report
December 26, 2003

An Agent Based Approach to Optimal Configuration Design with Application to Manufacturing Process Planning

Grant # F49620-01-0050

Jonathan Cagan
Department of Mechanical Engineering
Carnegie Mellon University
Pittsburgh, PA 15213

Summary

This project explored an agent based strategy for configuration design. A bulk manufacturing process planning problem served as the focus, but the methods and algorithms are readily extendible to any serial configuration and parameter instantiation problem.

The project focused on 3 goals:

1) Process instantiation. A probabilistic approach was used to determine which agents to select to instantiation a configuration through parameter selection.
2) Configuration optimization: The parameter optimization algorithm was modified to select and optimize sequences as well as optimize parameters. The advantage of the approach is that it is open-ended; there is no preconceived assumption of what sequences might be valid or optimal. Configuration agents were developed and integrated with the parameter agents to effectively optimize both process selection and parameters, concurrently.
3) Effective management of the agent process: Two approaches were taken. First, a strategy for learning across problems using findings in cognitive science was applied to our agent-based method. Second, using organizational models, a collaborative approach was formalized and implemented, allowing the agents to interact and make group decisions of how to best solve the configuration and parameter optimization problem.

In our algorithm the agents are modeled on manufacturing processes and contain domain knowledge specific to bulk manufacturing, the agents then develop a population of designs and modify it in a collaborative framework. The agent based optimization is based on domain knowledge and a stochastic search process. The parameter optimization algorithm has been shown to be more effective than the results found in the literature from an efficiency viewpoint.

Our configuration optimization algorithm was applied to the bulk manufacturing problem. We were able to confirm that one of the sequences used in the sample problem in other research and by WPAFB was the optimal sequence. We also showed that had the cost functions for manufacturing taken into account the effect of strain, then a different sequence was possible. In our example we found a process sequence where one of the manufacturing processes needed to be repeated to obtain the best process design.

Our work on agent collaboration has produced significant results. For the same problem, the collaborative algorithm finds final designs of 30% improvement, but also finds on average designs that are 65% better. The new algorithm also finds significantly more feasible designs. Most important is this approach uses high level strategies and statistics from the algorithm's history to make configuration changes, it is no longer dependent on domain knowledge about the application. Thus all of these results are readily applicable to any serial configuration problem.

In addition, the project was expanded to explore cognitive models of design to both better understand the design process and to begin to transfer that understanding into the computational agent models. Collaboration with Prof. Kenneth Kotovsky of the Dept. of Psychology at Carnegie Mellon explored human learning gained through expertise, in particular as students mature from freshmen to senior year. The focus was on electromechanical devices and both form descriptions and functional decompositions were investigated to better understand functional reasoning. To understand how people reason about functionality of devices a technique known as LSA (Latent Semantic Analysis) was used to evaluate people's descriptions of the mechanics of devices. The technique was implemented and tested and shows promise as both an evaluative technique and also a means to explore more fundamental aspects of creativity.

Collaborations with Kotovsky also led to a learning approach to allow the agent algorithm to learn across problem applications and domains, enabling for improved efficiency over repetitive applications.

Personnel Supported

Faculty: Prof. Jonathan Cagan, Prof. Kenneth Kotovsky (year 3)
Graduate students: Saurabh Deshpande (full support: Mechanical Engineering student obtained MS in May, 2001), Jarrod Moss (partial support: Psychology PhD candidate expected completion in May, 2005), Jesse Olson (full support: Mechanical Engineering student obtained MS in May, 2003; currently PhD candidate expected completion in May, 2005)

Publications Supported by Grant

Journal Publications

Deshpande, S., and J. Cagan, "An Agent Based Optimization Approach to Manufacturing Process Planning", in press: *ASME Journal of Mechanical Design*, 2004

Olson, J. T., and J. Cagan, "Inter-Agent Ties in Team-based Computational Configuration Design", accepted: *AI EDAM – Special Issue on Agents in Design*, 2003.

Moss, J., J. Cagan, and K. Kotovsky, "Learning from Design Experience in an Agent-Based Design System", submitted to: *Research in Engineering Design*, 2003.

Moss, J., K. Kotovsky, and J. Cagan (in preparation), "Expertise Differences in the Mental Representation of Mechanical Devices in Engineering Design," to be submitted to *Design Studies*, 2004.

Conference Publications

Deshpande, S., and J. Cagan, "An Agent Based Optimization Approach to Manufacturing Process Planning", to appear: *Proceedings of the 2001 ASME Design Engineering Technical Conferences: Design Automation Conference, DETC2001/DAD-21032*, September 9-12, Pittsburgh, PA, 2001.

Moss, J., J. Cagan, and K. Kotovsky, "Learning from Design Experience in an Agent-Based Design System", Proceedings of: International Workshop on Agents in Design – WAID'02, MIT, Cambridge, MA, 28-30 August, 2002.

Moss, J., Kotovsky, K., & Cagan, J., "Cognitive Principles in a Computational Engineering Design Methodology," In W. Gray and C. Schunn (Eds.), *Proceedings of the Twenty-Fourth Annual Conference of the Cognitive Science Society*, Mahwah, NJ., 2002

Olson, J. T., and J. Cagan, "A Collaborative Team-Based Approach to Computational Configuration Design: Initial Results," *2003 ASME Design Theory and Methodology Conference*, Chicago, September, 2003.

Moss, J., Kotovsky, K., Cagan, J., "Knowledge Representation in Engineering Design: An Initial Investigation," *Proceedings of the Twenty-Fifth Annual Conference of the Cognitive Science Society*, 2003

Moss, J., Kotovsky, K., Cagan, J., "Cognitive Investigations into Knowledge Representation in Engineering Design," submitted to: *Design Computation and Cognition 2004*, Cambridge, 2004